Extravehicular Activity	Console Position: EVA
Reactions, Electrochemistry, Stoichiometry Thermodynamics and States of Matter	

Extravehicular Activity (EVA) Life Support System (LSS)

How is a Livable Environment Maintained for Crewmembers While on a Spacewalk?

Instructional Objectives

Students will

- determine the standard reduction potential for a galvanic cell;
- calculate the ΔG°_{rxn} for the reaction;
- calculate the equilibrium constant, *K*, for the reaction;
- determine the heat transferred between the system and the surrounding;
- predict interaction between ions;
- write a balanced equation for the reaction; and
- determine the mass and volume relationship.

Degree of Difficulty

This problem requires students to integrate several aspects of the AP Chemistry curriculum to obtain the solution. For the average AP Chemistry student, the problem may be moderately difficult.

Total Time Required

Teacher Prep Time: 5–10 minutes

Class Time: 60–80 minutes

(To decrease amount of class time, students may complete research as homework via the Internet using the ISSLive! website or mobile application.)

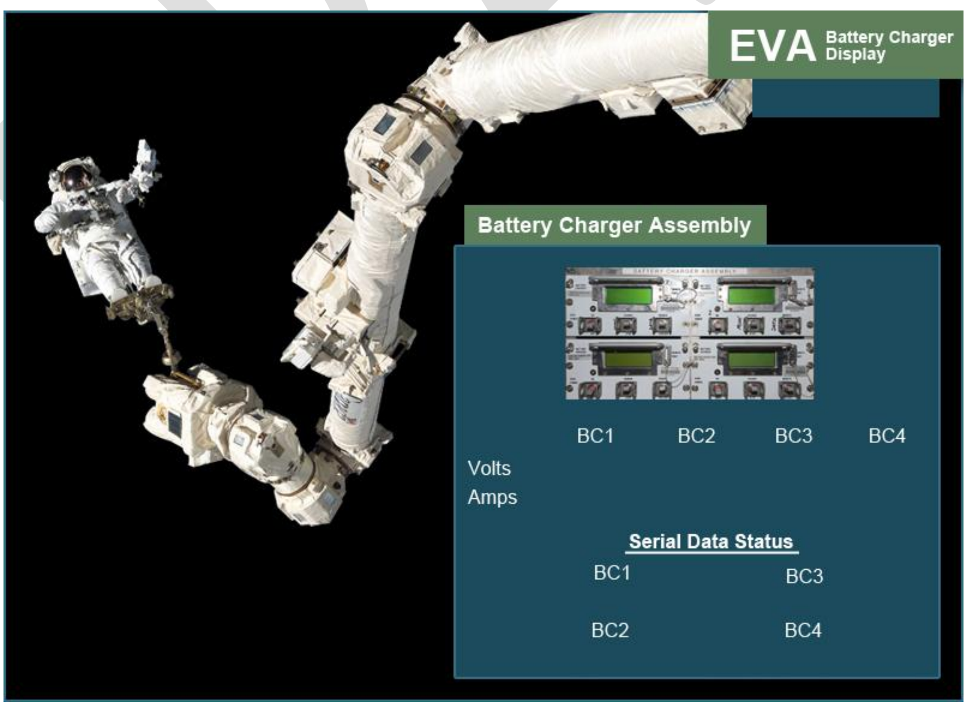
- Introduction: 5–10 minutes
- Student Research: 20–25 minutes
- Student Work Time: 25–30 minutes
- Post Conclusion: 10–15 minutes

Lesson Development

This problem is part of a series of problems associated with the NASA International Space Station *Live!* (ISS*Live!*) website at http://spacestationlive.jsc.nasa.gov.

Teacher Preparation

- Review the Extravehicular Activity information on the ISS*Live!* website. This may be found at the *Operations* tab, under *Core Systems*.
- Review the Extravehicular Activity (EVA) Handbook, paying specific attention to the Life Support System (LSS). This handbook may be found at the EVA console position in the 3D Mission Control Center environment (under the *Interact* tab, then *Explore Mission Control*).
- Review the EVA console display in the 3D Mission Control Center environment and the live data associated with the LSS. The displays may be accessed by clicking on the console screens.



EVA Console Display

- Review the interactive activity at the EVA console position in the 3D Mission Control Center environment *by clicking on the rocket* on top of the console. This activity demonstrates the operations of the LSS.
- Prepare copies of the STUDENT WORKSHEET (Appendix B).

Inquiry-Based Lesson (Suggested Approach)

1. Pose this question to the class:

   How is a livable environment maintained for crewmembers while on a spacewalk?

2. Allow students to discuss the question in small groups or as a class. Have students build their own questions and possible solutions to the problem.
3. Distribute the STUDENT WORKSHEET to the class. Students may work individually or in small groups (2–3 members per group) to conduct the research. This may be assigned as homework.
4. In order to conduct the research students should access the ISS*Live!* website and explore the 3D Mission Control Center. If needed, guide students to the EVA console position. They should access the EVA Handbook and EVA console displays, as well as the interactive activity, as they prepare to answer the questions on the STUDENT WORKSHEET.
5. Once the research is completed, students may work individually to complete the questions on the STUDENT WORKSHEET. They should refer to the live data on the EVA console displays located on the ISS*Live!* website to answer the entire problem.

Post Conclusion

6. A SOLUTION KEY (Appendix A) is provided below using data that is typical for normal operations of the LSS. Students' answers will vary depending on the actual live data.
7. Have students discuss their answers in small groups or with the entire class and tie back to the original question:

   How is a livable environment maintained for crewmembers while on a spacewalk?

8. Ask students to explain the LSS and the data they used in their calculations.
9. Assessment of student work may be conducted by using the provided rubric (modeled after AP Free Response Question scoring).

Extension

Other possible uses for the ISS*Live!* website, focusing on EVA and the Life Support System:

- Students can use the ideal gas law to calculate the mass of oxygen gas inside the spacesuit. Suit volume is 113.27 liters, suit pressure is 235.6 mmHg, and the temperature is 26.7°C.

AP Course Topics

States of Matter

- Gases
    - Laws of state for an ideal gas
    - Partial pressures

Reactions

- Oxidation-reduction reactions
    - The role of the electrons in oxidation-reduction
    - Electrochemistry: electrolytic and galvanic cells. Faraday's laws; standard half-cell potentials; prediction of the direction of redox reactions
- Stoichiometry
    - Mass and volume relations with emphasis on the mole concept
- Thermodynamics
    - Relationship of change in free energy to equilibrium constants and electrode potentials

NSES Science Standards

Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Science in Personal and Social Perspectives

- Science and technology in local, national and global challenges

Physical Science

- Chemical reactions
- Conservation of energy and increase in disorder

Science and Technology

- Abilities of technological design
- Understanding about science and technology

History and Nature of Science

- Science as a human endeavor
- Nature of scientific knowledge

Contributors

This problem is part of a series of problems developed by the ISS*Live!* Team with the help of NASA subject matter experts.

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NASA Expert
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Scoring Guide

Suggested 15 points total to be given.

Question		Distribution of points
1a	*1 point*	1 point for the correct standard reduction potential
1b	*1 point*	1 point for the correct half-reaction at the anode
1c	*2 points*	1 point for the correct set up to calculate $\Delta G°_{rxn}$ 1 point for the correct calculation of the $\Delta G°_{rxn}$
1d	*1 point*	1 point for the correct explanation for $\Delta G°_{rxn}$ at 0
1e	*1 point*	1 point for the correct equilibrium constant for the reaction
1f	*1 point*	1 point for determining the correct number of batteries
1g	*1 point*	1 point for the correct justification
2a	*1 point*	1 point for the correct change in temperature
2b	*1 point*	1 point for the correct calculation of heat transferred
2c (i) **2c (ii)**	*1 point* *1 point*	1 point for the correct balanced reaction 1 point for the correct explanation
3a	*2 points*	1 point for the correct setup to calculate moles of oxygen gas 1 point for the correct calculation of oxygen gas
3b	*1 point*	1 point for the correct explanation

APPENDIX A

SOLUTION KEY

EXTRAVEHICULAR ACTIVITY (EVA) LIFE SUPPORT SYSTEM (LSS)

How is a Livable Environment Maintained for Crewmembers While on a Spacewalk?

The Extravehicular Activity (EVA) Life Support System is primarily monitored and controlled by the Extravehicular Activity (EVA) flight controller. The EVA flight controller works in the Mission Control Center for the International Space Station (ISS), along with a team of other flight controllers. These flight controllers monitor the operations during a spacewalk to maintain a safe environment inside the space suit and success of the mission. To learn more, explore the 3D ISS Mission Control Center by accessing Explore Mission Control under the *Interact* tab on the ISS*Live!* website at http://spacestationlive.jsc.nasa.gov.

The Extravehicular Mobility Unit (EMU) is a suit system that provides the crewmember with protection, mobility, life support and communication during spacewalks, or EVA. To meet the crewmember's needs during the spacewalk, the EMU features several unique systems which help keep him or her safe and support a successful EVA. The EMU is equipped with a Life Support System (LSS) which is a group of systems and equipment that keeps a livable environment inside the EMU. These systems supply oxygen, stable pressure and air movement to the EMU.

1. In order to run the systems and equipment within the EMU, the suit must be equipped with battery packs. There are several types of batteries used to power the suits' equipment. Lithium batteries power up the suit, a nickel metal hydride battery is used for the lights and heated gloves, and nickel cadmium is used to power the drill. Based on the information provided, answer the following questions related to chemical reactions involving the nickel metal hydride battery.

   The reaction between nickel metal hydride and nickel oxyhydroxide is represented by the following equation (where M represents a metal):

   $MH + NiOOH \rightarrow Ni(OH)_2 + M \qquad E^\circ_{rxn} = +1.35\ V$

   a. Using the information above and in the table below, calculate the standard reduction potential, E°, for the reduction of NiOOH in a basic solution.

Half-Reaction	Standard Reduction Potential, E°
$M + H_2O + e^- \rightarrow MH + OH^-$	-0.82 V
$MH + NiOOH \rightarrow Ni(OH)_2 + M$	?

$E°_{rxn} = E°_{oxd} + E°_{red}$

$1.35 \text{ V} = 0.82 \text{ V} + E°_{red}$

$E°_{red} = 0.53 \text{ V}$

b. Which half-reaction takes place at the anode?

$M + H_2O + e^- \rightarrow MH + OH^-$

c. Calculate the value of the standard free energy change, $\Delta G°_{rxn}$, for the overall reaction between the metal hydride and nickel oxyhydroxide.

$\Delta G°_{rxn} = -nFE°$

$\Delta G°_{rxn} = -\ (1)\ (96{,}500 \text{ C})\ (1.35 \text{ V})$

$\Delta G°_{rxn} = -130{,}175.00$ J/mol or -130.175 kJ/mol

d. What occurs if the $\Delta G°_{rxn}$ value is equal to 0 for the cell?

When $\Delta G°_{rxn}$ is equal to zero, the battery is at equilibrium and is dead.

e. Calculate the equilibrium constant for the cell at 25°C.

$\Delta G°_{rxn} = -RT\ln K$

$$\Delta G°_{rxn} = -\left(8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}}\right)(298\,K)\ln K$$

$$-130{,}175.00 \frac{\text{J}}{\text{mol}} = -\left(2477.57 \frac{\text{J}}{\text{mol}}\right)\ln K$$

$\ln K = 52.54$

$K = 6.58 \times 10^{22}$

f. The EMU suit battery pack consists of multiple sets of batteries that supply power to different parts of the suit, including batteries that supply power for the suit's heated gloves. When the batteries providing power to the heated gloves are fully charged, the voltage reads approximately 16.0 V. If each battery provides approximately 1.2 V, how many batteries are wired in series to create the total charge? (Based on the half-reactions, the cell potential was 1.35 V in part a., but the actual discharge is 1.2 V.)

16.0 V / 1.2 V = 13.33, so 14 batteries are required to achieve the total charge.

g. Based on your knowledge of space environment, why would a battery failure to the glove heaters be significant in a 6 ½ hour EVA?

In space, there is extreme fluctuation in temperature. In the Sun's light, the temperature can reach up to 250 °F (121°C). Away from the Sun, temperatures drop to -250°F (-157°C). During the extreme cold durations, the crew could suffer from hypothermia if heat is not supplied to the body.

2. The equipment and the body inside the EMU produce heat. To maintain a comfortable environment, some of this heat must be removed. This must be addressed as crewmembers preparing for a spacewalk spend several hours inside the EMU before leaving the ISS. Inside the suit, each crewmember wears a Liquid Cooling and Ventilation Garment (LCVG) under the EMU that is equipped with coolant loops. These loops circulate cool water to absorb the heat within the suit. The heat is removed from the LCVG using the Low Temperature Loop (LTL) of the Internal Thermal Control System (ITCS), which is located onboard the ISS and is monitored by the ETHOS console. The average increase in temperature of the LTL during preparation for an EVA is to 16.5°C. (Visit the ETHOS console display to learn more about the LTL.)

   a. Visit the ETHOS console displays for the initial temperature of the ITCS and to determine the change in temperature after heat has been transferred from the LTL to the ITCS.

      Before heat absorption = Assumed value from ETHOS console of 11.0°C

      After heat absorption = 16.5°C

      $\Delta T = 16.5°C – 11.0°C = 5.5°C$

   b. The specific heat of water is 4.184 J/g·°C and the mass of water in the LCVG coolant loop is approximately 0.26 kg (0.58 lb). Calculate the amount of energy transferred from the LCVG to the ITCS.

      $q = m \cdot Cp \cdot \Delta T$

      $m = 0.26$ kg or 260.0 g

      $Cp = 4.184$ J/g·°C

      $\Delta T = 5.5°C$

      $q = (260.0\ g)\ (4.184\ J/g \cdot °C)\ (5.5°C)$

      $q = 6000$ J or 6.0 kJ

   c. Besides US EMUs onboard the ISS, there are also Russian spacesuits called Orlan suits, or Orlans. The Orlan is capable of hooking up to the US airlock and it uses the same voltage as a US suit for power. It is important that both suits keep microbial growth out of the water loop. In the EMU, microbial growth in the water is controlled by iodine ions; in the Orlan, a silver ion solution is used.

      i. Write the reaction that would occur if a US water bag used to replenish the EMU was accidently filled with the Russian silver biocide, and was later used to recharge the US EMU containing iodine ions.

$I^-(aq) + Ag^+(aq) \rightarrow AgI(s)$

ii. What effect could this have on the loops within the EMU?

Silver iodide forms a precipitate and could clog the loop of the EMU.

3. Oxygen gas also has to be supplied to each crewmember wearing an EMU on an EVA. The ISS has two EVA oxygen tanks used to fill EMU tanks which are located on the outside of the airlock. Since they are located on the outside of the ISS, heaters and insulation are used to maintain the temperature of the oxygen tanks at approximately 23.61°C. The volume of each tank is 430.42 L.

   d. Visit the EVA console display to determine the pressure of an EVA oxygen tank, and calculate the mass of oxygen gas available for an EVA.

   Assumed pressure value from the EVA console = 19,156.21 mmHg

   $$19{,}156.21\,\text{mmHg} \cdot \frac{1\,\text{atm}}{760\,\text{mmHg}} = 25.21\,\text{atm}$$

   $PV = nRT$

   $$(25.21\,\text{atm})\,(430.42\,\text{L}) = n\left(0.0821\frac{\text{atm}\cdot\text{L}}{\text{mol}\cdot\text{K}}\right)(296.61\text{K})$$

   n = 445.6 moles of oxygen gas are inside an EVA oxygen tank

   e. The ISS is always traveling through debris in its orbital path. Discuss a problem that could arise if debris were to hit the EVA oxygen tank and rip the insulation.

   The tanks are pressurized. A rip in the insulation would expose the tank to the extreme temperatures of space, 250°F (121°C) in the Sun. Pressure and temperature are directly proportional; the temperature increase would cause the pressure to increase. This could lead to the tank exploding under high pressure caused by the elevated temperatures.

APPENDIX B

STUDENT WORKSHEET

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c. Calculate the value of the standard free energy change, $\Delta G°_{rxn}$, for the overall reaction between the metal hydride and nickel oxyhydroxide.

d. What occurs if the $\Delta G°_{rxn}$ value is equal to 0 for the cell?

e. Calculate the equilibrium constant for the cell at 25°C.

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